1990

KIVA, *Vol. 56, No. 1, 1990*

NEUTRON ACTIVATION OF DOGOSZHI STYLE CERAMICS: PRODUCTION AND EXCHANGE IN THE CHACOAN REGIONAL SYSTEM

JILL E. NEITZEL
Department of Anthropology and Geography
William Patterson College of New Jersey
Wayne, NJ 07470

RONALD L. BISHOP
Conservation Analytical Laboratory
Smithsonian Institution
Washington D.C. 20560

ABSTRACT

Neutron activation analysis was carried out on 60 Dogoszhi style black-on-white ceramic vessels from three prehistoric Chacoan sites in the northern U.S. Southwest. Cylinder vessels and bowls from Pueblo Bonito and Pueblo del Arroyo, two large towns located in Chaco Canyon, New Mexico, exhibited a high degree of compositional homogeneity. However, bowls from the community associated with the outlying town of Allentown were compositionally different, suggesting that they were manufactured at a different location. Comparisons with the results of neutron activation analyses obtained previously for Dogoszhi style sherds from Black Mesa, Arizona, revealed that these ceramics also were compositionally different from those found in Chaco Canyon.

RESUMEN

Se realizó un análisis de activicíon neutrón en 60 estilo Dogoszhi negro-sobre-blanco vasijas cerámicas de tres sitios prehistóricos Chaco en el norte del Suroeste Americano. Las vasijas en cinlindro y escudillas desde Pueblo Bonito y Pueblo del Arroyo, dos pueblos grandes colocados en el Cañon Chaco en Nuevo México, mostraron un alto grado de homogeneidad composicional. Sin embargo, escudillas asociadas con la periférica comunidad de Allentown eran composicionalmente diferente, indicando que fueron hechas en un sitio diferente. Una comparaciòn de los resultos de un análisis de activición neutrón previamente obtenidos de cascos estilo Dogoszhi de Black Mesa, Arizona, indica que estas cerámicas tambien eran composicionalmente diferentes a las del Cañon Chaco.

A unique style of black-on-white pottery was associated with the hierarchically organized regional system that was centered around Chaco Canyon, New Mexico between A.D. 900 and 1200 (Figure 1). This style is known as Dogoszhi; and it consists solely of hatched designs (Hantman and others 1984). In this paper, neutron activation analysis is used to address four questions concerning the production and exchange of Dogoszhi style ceramics.

PREVIOUS ANALYSES OF CHACOAN CERAMICS

Most previous research on decorated ceramics from Chaco Canyon and its surrounding region has been concerned primarily with defining pottery types and

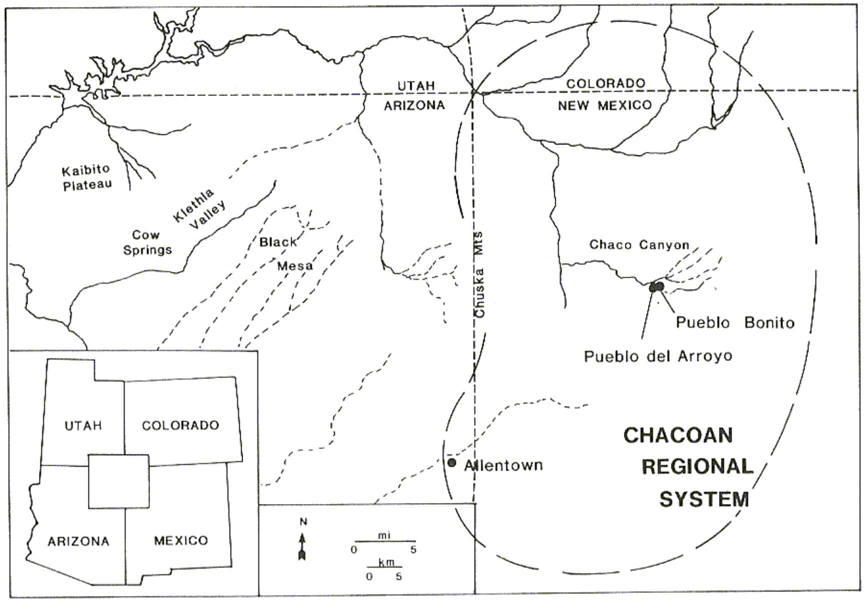
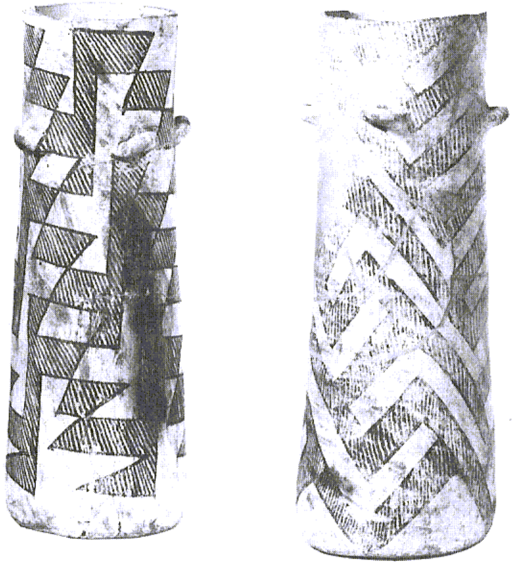


Figure 1. Map of the northern Southwest showing locations discussed in this paper.

then refining these definitions in order to construct more precise chronological sequences (for example, Roberts 1927; Windes 1984). With one notable exception (Shepard 1939), it has only been recently that the problem of spatial variation has begun to be addressed through paste compositional analyses (Franklin 1982; McKenna 1984; Toll 1981, 1984, 1985; Toll and others 1980). The results of these analyses have provided evidence for the magnitude, complexity, and extent of ceramic exchange in the Chacoan regional system.

For example, between A.D. 1100 and 1200 approximately one-half of the ceramics found in Chaco Canyon were imported (Toll 1985:127). The most important source area was the Chuska Mountains, approximately 75 km to the west of the canyon (Figure 1). This source has been identified on the basis of a distinctive basalt temper, called trachyte or sanidine basalt, that occurs naturally in only two deposits in the Chuska area (Loose 1977; Warren 1967). Between A.D. 1100 and 1200, one-third of the ceramics found in Chaco Canyon, including approximately one-half of the culinary wares and one-fourth of the white wares, contained this temper (Toll 1985:126; also see Hawley 1934; Judd 1954, 1959; Shepard 1939). The fact that only isolated pieces of trachyte have been found within the canyon (Windes 1977) makes it seem unlikely that this temper was being imported in its raw form for local ceramic production. Instead, canyon residents were apparently receiving finished vessels from manufacturing centers located most probably in the Chuska area.



a b

Figure 2a. Example of Dogoszhi style cylinder vessel from Room 329 at Pueblo Bonito (courtesy of the Department of Anthropology, National Museum of Natural History, Smithsonian Institution; catalogue number 336496). **b.** Example of Dogoszhi style cylinder vessel from Room 329 at Pueblo Bonito (courtesy of the Department of Anthropology, National Museum of Natural History, Smithsonian Institution; catalogue number 336498).

Spatial variation in design styles has received the least attention in discussions about Chacoan ceramics. Neitzel (1991) and Plog (1990, 1991) have suggested that the hatched designs comprising the Dogoszhi style served as a symbol of Chacoan economic, political, and ceremonial power. Neitzel (1991) has proposed that the Dogoszhi style was an elite style within the Chacoan regional system. This hypothesis has been supported by distributional analyses that revealed discrete drops in the relative occurrence of Dogoszhi style pottery within each successively lower level of the Chacoan settlement hierarchy. Outside the Chacoan regional system on Black Mesa in northeastern Arizona, the ceremonial significance of the Dogoszhi style has been supported by Plog's (1990, 1991) discovery of significantly higher frequencies of this pottery at sites with kivas.

CYLINDER VESSELS

The most unusual Dogoszhi style ceramics are the cylinder vessels (Figure 2) that have been recovered almost exclusively from Pueblo Bonito, the largest excavated site in Chaco Canyon. Pueblo Bonito is a four-story structure containing almost 700 rooms and 36 kivas (Judd 1964; Pepper 1920). Together, the central location and large size of this settlement suggest that it was the most important of the more than 50 towns that comprised the Chacoan regional system (Hayes and others; Judge 1979; Marshall and others 1979; Neitzel 1989a; Powers and others 1983; Schelberg 1982). Mortuary and artifactual data from Pueblo Bonito indicate that the site functioned as both a center for long distance trade and the residence of high status individuals (Neitzel 1989a, 1989b).

Of the 207 cylinder vessels that have been recorded in the American Southwest, 191 of them were excavated at Pueblo Bonito (Toll 1985:204-205). Washburn (1980) has suggested that these specimens were imitations of forms made in Mesoamerica. She also believes that the cylinder vessels from Pueblo Bonito were mass produced by a few craft specialists for special purposes. Washburn's evidence for specialized production is the high degree of uniformity in both the sizes of the vessels and the designs used to decorate them (Figure 2). Her evidence for special function is the contexts in which the vessels were found and the wear patterns that some of them exhibit. Almost three-quarters of the cylinder vessels from Pueblo Bonito were recovered from a cache in one room (28); and another 14 percent were associated with high status burials. In addition, the interiors of some of the vessels were scratched after firing by hard, sharp objects. Washburn has concluded that the cylinders were used by high status individuals to store such luxury goods as turquoise and shell.

The designs that were used to decorate cylinder vessels were almost all done in the Dogoszhi style (Neitzel 1985). Approximately three-quarters of those vessels in the cache in Room 28 were painted exclusively with hatched designs. The same percentage of Dogoszhi style decoration was found on painted cylinder vessels from contexts other than the Room 28 cache. This percentage is more than one and one-half times greater than both the relative occurrence of Dogoszhi style ceramics at the site of Pueblo Bonito as a whole and the average occurrence of this style in caches of more than 10 pots in rooms other than Room 28.

To date, there has been no systematic effort to identify where the Chacoan cylinder vessels were made. However, observations by Toll (1985:207) suggest one probable source. Many of the cylinder vessels examined by Toll and his colleagues were made with trachyte temper. The logical conclusion is that cylinder vessels were being manufactured in the Chuska area and then traded almost exclusively to the residents of Pueblo Bonito in Chaco Canyon.

Given our present knowledge about the manufacture, decoration, and function of cylinder vessels, two questions can be asked:

1. Is there evidence that the Dogoszhi and non-Dogoszhi style cylinder vessels from Pueblo Bonito differed in the raw materials used in their manufacture and/or in the organization of the activities involved in their production?
2. Is there evidence that the cylinder vessels and other Dogoszhi style ceramics found at Pueblo Bonito differed in the raw materials used in their manufacture and/or in the organization of the activities involved in their production?

These questions have been phrased so that they can be addressed through ceramic compositional analyses. Their purpose is to ascertain whether the production of Dogoszhi style cylinder vessels differed in some way from the production of non-Dogoszhi cylinder vessels or from other vessel forms decorated in the Dogoszhi style. Unfortunately, while ceramic compositional analyses can provide evidence of differences in production, they cannot, in and of themselves, reveal the nature of these differences (Bishop 1980; Bishop, Rands, and Holley 1982). Thus, the presence of compositional variation could indicate that the vessels being compared were made in different places or else that they were made in the same place by potters who relied on different sources of raw materials.

In either of these two situations, ceramic exchange may have contributed to the observed variation. However, questions about the nature and relative importance of this exchange can be difficult to answer for two reasons. First, it may be impossible to determine on the basis of compositional analyses alone whether raw materials or finished vessels were being traded. Second, since the elemental profiles produced by compositional analyses represent the combined effects of all of the components of ceramic paste, it may not be clear whether the exchange of raw materials involved clay, temper, or both.

In order to begin to answer questions about the production and exchange of Dogoszhi style cylinder vessels, clay samples from 44 whole pots were subjected to neutron activation analysis. These ceramics were excavated by the National Geographic Society (Judd 1954, 1959) and are now part of the collections of the National Museum of Natural History at the Smithsonian Institution. They included 11 cylinder vessels from Pueblo Bonito, 1 cylinder vessel from the nearby town of Pueblo del Arroyo (Figure 1), and 32 randomly selected Dogoszhi style bowls from Pueblo Bonito. Eight of the cylinder vessels were decorated solely with hatched designs (7 from Pueblo Bonito, 1 from Pueblo del Arroyo); and two were undecorated. The other two cylinder vessels were decorated with a combination of either solid lines and solid triangles or solid lines and hatched triangles. Dogoszhi style bowls were selected for comparative purposes in order to obtain better control over functional variation than is possible with the more amorphous category of jars.

Samples of ceramic paste from each of the vessels were activated at the reactor facility at the National Institute of Standards and Technology (formerly National Bureau of Standards) (Appendix A). The elemental profiles obtained for each sample were then compared with the aid of multivariate statistical techniques (Appendix B). The purpose of these analyses was to determine whether or not archaeologically meaningful groups of compositionally different vessels could be identified.

No effort was made prior to the neutron activation analyses to sort the vessels according to the types traditionally used by Southwestern archaeologists. There were several reasons for our not using types. First, given recent criticisms of the typological aproach for dating purposes (for example, Plog and Hantman 1986) as well as our confidence that all of the vessels in our sample were at least roughly contemporaneous, we saw no reason to use types for chronological control. Second, given the doubts that have been raised about the value of the typological approach for addressing questions about production and exchange (for example, Hantman and Plog 1982), we saw no benefit in using types in conjunction with the neutron activation analyses. Also, since we wanted to document overall compositional variability, we needed to examine all of the vessels together, not to compare already separated groups of vessels. One final practical consideration that affected our decision not to use types was the fact that we were dealing with whole vessels in a museum collection. Consequently, we could not make the breaks that are necessary for reliable temper identification, an essential step in distinguishing Southwestern types.

In general, the results of the neutron activation revealed no statistically significant compositional differences among the majority of the cylinder vessels or between the cylinder vessels and most of the Dogoszhi style bowls from Pueblo Bonito. The Dogoszhi style cylinder vessel from Pueblo del Arroyo was apparently made of the same raw materials as the Dogoszhi style cylinder vessels from Pueblo Bonito; and all but three of these vessels were compositionally the same as those that were undecorated or decorated in another style. Similarly, the cylinder vessels could not be separated on the basis of their elemental profiles from all but seven of the Dogoszhi style bowls that were excavated from Pueblo Bonito.

Two explanations can be proposed to account for this compositional homogeneity. The most obvious is that the cylinder vessels and Dogoszhi style bowls from Pueblo Bonito were all being made in a restricted region with clays and tempers obtained from similar sources. Perhaps the most logical location for this pottery production would be Chaco Canyon itself. However, Toll's (1985:207) observations of trachyte temper in cylinder vessels raise the possibility that the vessels analyzed for this study were made in the Chuska area and then traded into the canyon. An alternative explanation for the observed compositional homogeneity is that these ceramics were being made in different regions with the same widely available raw materials (Toll 1985:103). In this case, either different clay and temper sources were compositionally the same or else clay and/or temper from particular sources were being widely traded.

DOGOSZHI VESSELS WITHIN THE CHACOAN REGIONAL SYSTEM

The results of the neutron activation of cylinder vessels and Dogoszhi style bowls from Pueblo Bonito raise the issue of whether the same compositional homogeneity is present in Dogoszhi style vessels at other Chacoan sites. Specifically, the question that can be asked is this: Is there evidence that Dogoszhi style ceramics from Pueblo Bonito differed from Dogoszhi style ceramics from other Chacoan towns in the raw materials used in their manufacture and/or in the organization of the activities involved in their production?

Neutron activation analysis was used to address this question for two sites whose collections are at the National Museum of Natural History at the Smithsonian Institution. One of these sites is the large canyon town of Pueblo del Arroyo, a 300-room structure that has 17 kivas and that is located less than 0.5 km from the contemporaneous Pueblo Bonito (Judd 1959) (Figure 1). The other site is the community that is associated with the medium-sized outlier of Allentown and that is located more than 125 km to the southwest of Chaco Canyon (Figure 1). While this town has yet to be excavated, subsurface investigations have been conducted in the 19 pithouses, 12 masonry rooms, and 2 kivas in its surrounding village (Roberts 1939, 1940). The results of these investigations suggest that the village was occupied between A.D. 1050 and 1175, the interval when Pueblo Bonito reached its peak in both size and influence (Powers and others 1983:2).

Samples of paste were removed from each of the whole Dogoszhi style bowls recovered from Pueblo del Arroyo (6) and Allentown (10). These samples were processed using the same procedures that had been applied in the analyses of the Pueblo Bonito ceramics (Appendix A). Again, bowls were selected for study in order to minimize the effects of functional variation between different vessel forms. Once the elemental profiles for each of the samples had been obtained, the data were added to that collected previously for the cylinder vessels and Pueblo Bonito bowls. Then, the same multivariate techniques that had been applied in the earlier analyses were used to determine whether compositionally distinct groups of vessels could be identified in the combined data set (Appendix B).

Two groups were defined. The larger one, which was used as the reference group in the statistical analyses, represented the specimens from Chaco Canyon. It included 9 of the 12 cylinder vessels, 25 of the 32 bowls from Pueblo Bonito, and 5 of the 6 bowls from Pueblo del Arroyo. One bowl from Allentown also was placed in this group. The second group consisted of the other nine bowls from Allentown and one bowl from Pueblo Bonito. Table 1 presents the elemental means and standard deviations for the two groups; and Figure 3 provides a graphical display of the relationship between them.

The axes on the graph in Figure 3 represent 2 of the 14 eigenvectors that were derived from the variance-covariance matrix of the Chaco group (Appendix B). Vector 10 (x axis) is heavily loaded with concentrations of the elements potassium, chromium, and lutetium, while vector 1 (y axis) is heavily loaded with concentrations of the elements cerium and samarium. The distribution of the data points representing the Chaco Canyon and Allentown specimens clearly shows the compositional distinctiveness of the two groups. All but two of the members of the Allentown group are located outside the 95 percent confidence ellipsoid defined

Table 1. Elemental Means and Percent Standard Deviations.

Element	Chaco Canyon[a] n = 40		Allentown n = 9		Black Mesa n = 60	
sodium	0.362	(30)	0.136	(31)	0.316	(59)
potassium	2.49	(15)	1.22	(51)	1.73	(21)
scandium	17.2	(10)	16.0	(10)	14.10	(10)
chromium	60.6	(21)	64.2	(13)	50.4	(17)
iron	2.05	(11)	1.78	(29)	1.57	(20)
rubidium	180.	(18)	74.5	(99)	107.	(24)
barium	599.	(27)	445.	(68)	800.	(30)
lanthanum	60.5	(10)	67.5	(13)	47.2	(19)
cerium	107.	(11)	121.	(21)	80.8	(22)
samarium	8.25	(13)	8.69	(31)	6.19	(25)
europium	1.59	(13)	1.63	(29)	1.10	(25)
ytterbium	3.94	(10)	4.37	(15)	3.01	(15)
lutetium	0.517	(15)	0.566	(13)	0.434	(15)
hafnium	6.82	(7)	7.28	(12)	5.69	(20)
tantalum	1.82	(22)	2.38	(36)	0.968	(33)
thorium	21.5	(8)	22.6	(16)	17.4	(20)

Note: Mean elemental concentrations are listed as parts per million except for sodium, potassium, and iron which are given in percent. The numbers in parentheses are one standard deviation on mean concentration expressed as percent. Data are reported at three significant figures.

a. Only the Chaco Canyon group has been rigorously defined.

for the Chaco group. The two Allentown specimens, which lie just inside the ellipsoid on this graph, are placed outside it on graphs comparing the other pairs of vectors.

These results suggest that Dogoshzi style bowls from Pueblo del Arroyo were being produced with the same materials as those from Pueblo Bonito. If separate clay and temper sources were compositionally different, then this production could have occurred either within the canyon or else at some other location, such as the Chuska area, with the finished products then being imported to the canyon sites. If different raw material sources were compositionally the same or if clay and/or temper from particular sources were widely traded, then the Dogoszhi style vessels found at the canyon sites could have been produced at a number of different locations.

The bowls from Allentown provide the first evidence for the localized production of Dogoszhi style ceramics. The majority of these vessels form a group that is compositionally different from that representing the Pueblo Bonito and Pueblo del Arroyo specimens. One possible interpretation of these results is that

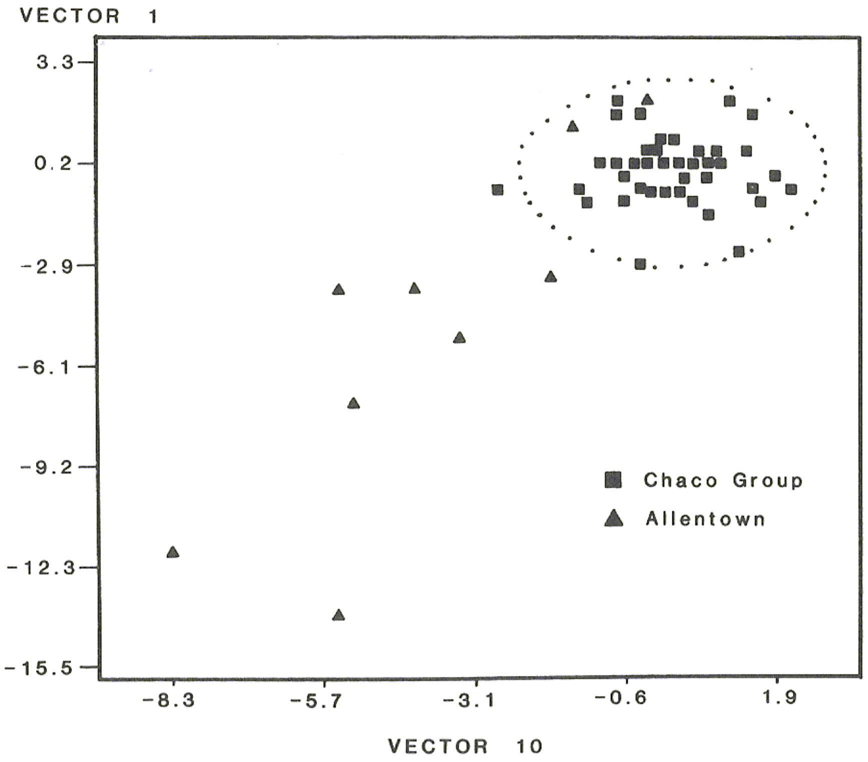


Figure 3. Plot of the Chaco Canyon and Allentown groups showing the 95 percent confidence ellipsoid for the Chaco group.

the Allentown vessels were being made at a different place than the vessels at Pueblo Bonito and Pueblo del Arroyo. The most logical location for this pottery production is Allentown itself. However, it is also possible that the ceramics were being produced elsewhere (but not at the same place as the Pueblo Bonito and Pueblo del Arroyo ceramics) and were then transported to Allentown. The fact that the Allentown group is less cohesive than the canyon group suggests either that the clay and temper sources used by the producers of the former group were compositionally more variable or that the manufacturing activities of these potters were in some way more variable.

The one Allentown bowl, which was compositionally the same as the cylinder vessels and bowls from Pueblo Bonito and Pueblo del Arroyo, was probably imported from the same source from which the canyon sites obtained their vessels, either the canyon itself or more likely the Chuska area. Of course, it is also possible that Allentown potters made this bowl from imported raw materials.

It should be noted that after the definition and refinement of the Chacò Canyon and Allentown groups, 10 of the original 60 specimens were left unplaced. These samples included six bowls and three cylinder vessels from Pueblo Bonito and one bowl from Pueblo del Arroyo. The divergent cylinder vessels were all decorated in the Dogoszhi style; and they showed little tendency to cluster with each other, suggesting that their divergence was due to different factors. One of these vessels had a marked elemental deviation of the rare earth concentrations. The other two had lower overall concentrations, suggesting the possible effects of temper or grain size on the elemental profiles (Bishop 1980). The divergent bowls were found to differ markedly from the large Chaco group in the standard deviations of several individual elements.

DOGOSZHI VESSELS OUTSIDE THE CHACOAN REGIONAL SYSTEM

Although Dogoszhi style ceramics are most strongly associated with the Chacoan regional system, they are also found in other areas at approximately A.D. 1050-1175. This interval represents the time of both the greatest cultural development within Chaco Canyon and the maximum extent of its surrounding regional system (Judge 1979; Powers and others 1983; Schelberg 1982). The issue of the external relations of the Chacoan regional system is raised by the presence of Dogoszhi style ceramics throughout the northern Southwest. A pertinent question that can be answered through compositional analyses is this: Is there evidence that Dogoszhi style ceramics from sites located outside the Chacoan regional system differed from Dogoszhi style ceramics from sites in Chaco Canyon in the raw materials used in their manufacture and/or in the organization of the activities involved in their production?

This question was addressed using the results of neutron activation analyses done previously by Deutchman (1979, 1980) whose data are stored in the Smithsonian Archaeometric Research Collections and Records (SARCAR) facility at the Conservation Analytical Laboratory of the Smithsonian Institution. Included in Deutchman's data are the elemental profiles of 109 Dogoszhi style bowl and jar sherds from 10 habitation sites from the Black Mesa region of northeastern Arizona (Figure 1). Based on the presence of several homogeneous compositional groups that appeared to covary with such archaeological variables as vessel shape and design, Deutchman (1979:177) suggested that the Dogoszhi sherds might have been imported to Black Mesa. Further research is necessary, however, to substantiate this interpretation.

Because Deutchman's neutron activation analyses were done at a different laboratory with procedures that are not identical to those currently used at the National Institute of Standards and Technology, her data first had to be made comparable to that obtained for the specimens from Pueblo Bonito, Pueblo del Arroyo and Allentown (Appendix B). These normalized data were then reanalyzed using the same multivariate techniques that had been been applied in the preceding analyses.

Our inspection of the initial cluster represented by a hierarchical dendrogram revealed no large, compositionally compact groups. Although the notion of a "compact" group is subjective and is defined relative to a specific problem (Bishop and Neff 1989), our finding was consistent with the results of Deutchman's own analyses. One weakly defined cluster whose members demonstrated considerable intragroup heterogeneity was selected to serve as a trial reference group and was subjected to refinement as described in Appendix B. This group contained 24 specimens from sites located on Black Mesa. Once statistically nonmatching specimens at the 95 percent confidence interval were removed and nongrouped samples lying within that interval were added, the resulting Black Mesa reference group consisted of 60 specimens, 35 from Black Mesa itself and 25 from sites located within 8 miles of the mesa (Table 1). The areas outside of the mesa included the Klethla Valley, the Cow Springs area, and the Kaibito Plateau.

For the samples from sites that were not well represented in Deutchman's data set, there was little indication of acceptable clustering tendency into archaeologically meaningful clusters. Two small clusters illustrate this pattern. One consisted of 13 samples, 5 of which were from site NA11,024 on the Kaibito Plateau; and the other consisted of 17 samples, one- third of which were from site NA11,125 in the Klethla Valley. None of the members of these two small, weakly defined groups lay within the 95 percent confidence interval for the Black Mesa reference group.

The presence of this compositional variation suggests that Deutchman's data may represent a mixed population that will be subdivided further once larger numbers of samples are analyzed. The association of groups of compositionally different sherds with different areas could be the result of either local production or external exchange. If Dogoszhi style ceramics were being produced locally in different parts of the Black Mesa region, then compositional differences could reflect differences in the raw material sources that were being used. Alternately, if Dogoszhi style ceramics were being imported, then they may have been obtained from production centers that relied on different clay and/or temper sources.

One conclusion that can be made at present is that if the residents of the Kaibito Plateau, the Klethla Valley and Black Mesa were importing their Dogoszhi style vessels, they were not obtaining them from the same place as the residents of Pueblo Bonito and Pueblo del Arroyo. When Deutchman's data were compared to that obtained in the present investigation, each of the sherds in her sample had less than a 1 percent probability of being a member of the large group of compositionally similar ceramics defined for Chaco Canyon.

Figure 4 provides a graphic display of the relationship between the Chaco Canyon, Allentown, and Black Mesa specimens (Appendix B). Although this plot

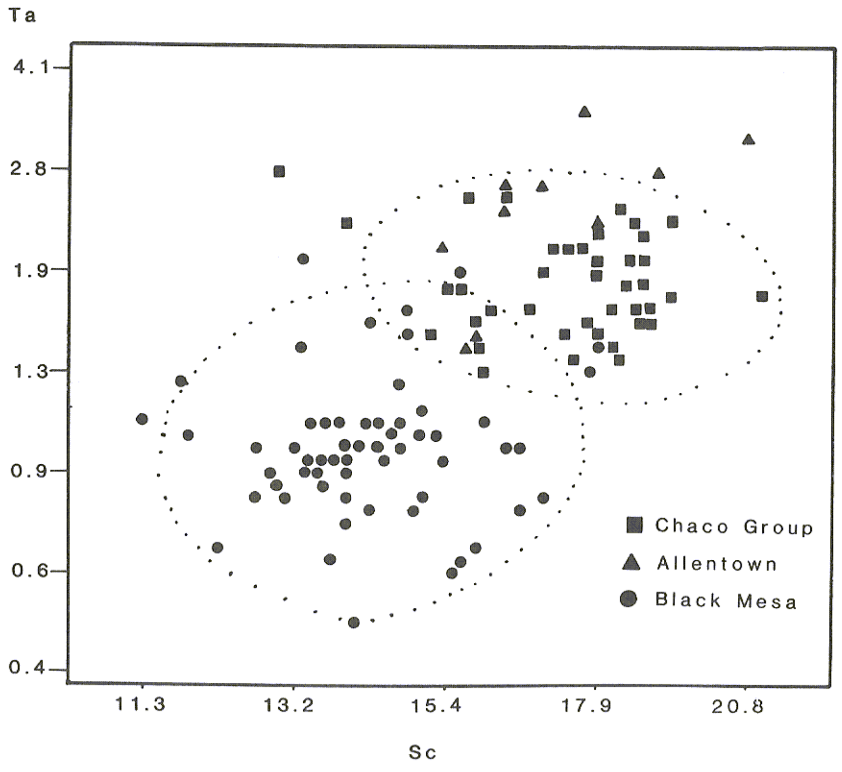


Figure 4. Plot of the Chaco Canyon, Allentown, and Black Mesa groups showing the 95 percent confidence ellipsoids for the Chaco and Black Mesa groups.

of the original data for the elements scandium and tantalum does show some overlap in the 95 percent confidence intervals, it also illustrates the distinctiveness of the Chaco and Black Mesa groups. Full separation occurs when all of the elements are considered at once.

CONCLUSION

The task of interpreting the results of neutron activation analysis is constrained by the problem of equifinality. The various explanations that have been proposed in this paper to account for the results of the compositional analyses done at Pueblo Bonito as well as at other sites both within and outside the Chacoan regional system illustrate how very different processes of ceramic production and exchange can be manifested in the same way in the archaeological record. Despite these difficulties, two conclusions can be made about the production and exchange of Dogoszhi style black-on-white pottery.

Table 2. Gamma Counting Parameters.

Nuclide Elements	Gamma Ray Analyzed	Energy (keV)	Count
sodium	Na-24	1369	1
potassium	K-42	1525	1
calcium	Sc-47	159	1
scandium	Sc-46	889	2
chromium	Cr-51	320	2
iron	Fe-58	1099 and 1292	2
cobalt	Co-60	1173 and 1333	2
zinc	Zn-65	1115	2
arsenic	As-76	559	1
bromine	Br-82	554	1
rubidium	Rb-86	1077	2
strontium	Sr-85	514	2
zirconium	Zr-95	757	2
antimony	Sb-122	564	1
cesium	Cs-134	796	2
barium	Ba-131	496	1
lanthanum	La-140	1596	1
cerium	Ce-141	145	2
neodymium	Nd-147	91	1
samarium	Sm-153	103	1
europium	Eu-152	1408	2
terbium	Tb-160	298	2
ytterbium	Yb-175	396	1
lutetium	Lu-177	208	1
hafnium	Hf-181	482	2
tantalum	Ta-182	1221	2
thorium	Pa-233	312	2
uranium	Np-239	106	1

First, there is no evidence that the cylinder vessels and Dogoszhi style bowls from Pueblo Bonito and Pueblo del Arroyo differed in the raw materials used in their manufacture and/or in the organization of the activities involved in their production. Any special purposes that cylinder vessels may have had were not reflected in the clays and tempers used in their manufacture. Similarly, if cylinder vessels were produced by specialists (Washburn 1980), then either the same individuals were also making Dogoszhi style bowls or else differences among potters were not reflected in the compositions of their products.

The second conclusion is that the Dogoszhi style ceramics found throughout the northern Southwest were not all being made at the same place. While the towns in Chaco Canyon may have exerted considerable influence on their surrounding region as well as on more distant areas, this influence was not manifested by the widespread exchange of ceramics from the canyon. Instead, potters in outlying areas apparently applied the style that predominated in the canyon to their own vessels.

Clearly, much more research is necessary to reconstruct the system of production and exchange that distributed Dogoszhi style ceramics both within and outside the Chacoan regional system. Most importantly, neutron activation analysis needs to be done on ceramics from more sites. The analyses presented here were limited to only those sites that had either whole vessels or neutron activation data stored at the Smithsonian Institution. The results have answered some questions and raised others such as: Were the Dogoszhi style ceramics at Pueblo Bonito and Pueblo del Arroyo being manufactured in the Chuska area? At how many other locations were Dogoszhi style ceramics being produced? What was the relative importance of these various manufacturing centers in terms of ceramic exchange? These questions can only be answered by compositional analyses of ceramics from sites located throughout the Chacoan regional system as well as other parts of the northern Southwest.

One question that remains unanswered is where the Dogoszhi style ceramics in the canyon were being made. The compositional homogeneity of the specimens from Pueblo Bonito and Pueblo del Arroyo suggests that they were being produced at the same place. However, the widespread exchange that has been documented previously in distributional analyses of trachyte tempered wares (Windes 1977) suggests that this production may have occurred in the Chuska area rather than the canyon itself. This hypothesis should be tested through the application of neutron activation analysis to Dogoszhi style ceramics collected from sites in the Chuska area.

Acknowledgments. Work at the National Institute of Standards and Technology was carried out by Bishop as a Guest Worker in the Nuclear Methods Group. Particular thanks are expressed to M. James Blackman of the Smithsonian Institution's Conservation Analytical Laboratory staff for facilitating the neutron activation analyses and for providing the conversion factors between the analytical reference standards of the National Institute of Standards and Technology and Brookhaven National Laboratory. We are also grateful to Bruce Smith, Dennis Stanford, Carolyn Rose, and Candace Greene for permission to remove samples of paste from Chacoan vessels in the collections of the Department of Anthropology, National Museum of Natural History. Catharine Valentour provided guidance during the sampling procedure. Finally, the compositional data for Dogoszhi style ceramics from Black Mesa were obtained from the dissertation research of Harec Deutchman. Deutchman's neutron activation analyses were done at Brookhaven National Laboratory in cooperation with the Department of Chemistry and under the auspices of the U.S. Department of Energy.

APPENDIX A: NEUTRON ACTIVATION

The investigation of the questions presented in this paper required the application of Instrumental Neutron Activation Analysis (INAA), a method of compositional analysis that is sufficiently sensitive to show subtle differences in the pastes used in ceramic manufacture. Such differences can be caused by variation in either the raw materials or the production techniques used by prehistoric potters.

The first step in INAA involves the removal of a small amount of paste from the sherds or vessels of interest. Samples for the analyses performed here were obtained by cleaning a small area on each of the 60 selected specimens and then extracting approximately 100-150 mg of ceramic paste from this area. To prevent contamination, the cleaned area was always slightly larger than the sampling location. The samples were taken with a tungsten carbide rotary file attached to the end of a flexible shaft, variable speed drill. In addition to its tungsten content, the file is known to contain trace amounts of other chemicals. If file contamination occurs, it can be seen in a sample's tungsten gamma peak intensity. Computational adjustments can be made to correct for the effects of such contamination.

Multi-elemental analysis of each sample was carried out in the reactor facility at the National Institute of Standards and Technology as part of its cooperative programs with the Conservation Analytical Laboratory. The samples and accompanying standard material of known elemental content, NBS Standard Reference Material SRM 1633 (Coal Fly Ash), were encapsulated and irradiated for six hours at a neutron flux of 7.7×10^{13} n/cm^2/sec. Following a six-day decay, each sample was counted for one hour using an intrinsic germanium detector (FWHM at 1333 60_{Co} of 1.71 keV). The count data were collected on an 8192- channel Nuclear Data ND6600 multichannel analyzer. Subsequent data processing and reduction of the gamma peak data to elemental concentrations included correction for pulse pileup and gamma peak interference. The samples were then allowed to decay for 30 days after which each sample was recounted for two hours. This irradiation and counting configuration can determine routinely the concentrations of as many as 28 elements. Gamma counting parameters are given in Table 2.

APPENDIX B: NUMERICAL ANALYSES

Numerical analyses of the data produced by the neutron activation proceeded through stages of group formation, evaluation, and refinement. Not all of the elemental determinations were utilized due to considerations of analytical precision and geochemical behavior (Bishop 1980; Bishop, Harbottle, and Sayre 1982; Harbottle 1982) as well as using only the elemental concentrations that are determined in common at the National Institute of Standards and Technology and Brookhaven National Laboratory. The analytical data produced at Brookhaven National Laboratory were normalized to conform with the analytical reference material (Coal Fly Ash) used as a standard at the National Institute of Standards and Technology.

Concentrates of 14 elemental determinations were transformed to their logarithms and used in varying combinations during the numerical analyses. As a first step, the data were submitted to a complete linkage, hierarchical cluster analysis using a matrix of sample-to-sample similarities based on Euclidean distance. Since this method of cluster analysis treats each elemental determination as a fully independent variable, the groups defined in the resulting dendrogram provide only a first approximation of the underlying structure of the data set. In fact, elemental measurements are not independent but rather can be highly correlated with one another (Harbottle 1976). Thus, additional analyses are necessary to evaluate and refine the defined groups in a manner that will incorporate information on elemental interdependence.

Accordingly, using the variance-covariance matrix for one of the defined groups and working under the assumption that its members were randomly drawn from a multivariate normal distribution, the probability that each of these samples was in fact a member of the group was calculated. This probability calculation is based on each sample's Mahalanobis distance from the multivariate group centroid. This distance is expressed as Hotellings T^2, which is the multivariate extension of the Student's t statistic. Samples found to lie outside of the 95 percent confidence interval were removed from the group. The variance-covariance matrix was then recalculated and the probabilities of group membership were reassessed.

A similar procedure can be used to evaluate the likelihood that samples defined initially as lying outside of the reference group were in fact members of that group. A not infrequent situation with dendrogrammatic representation is that some "natural" group, which forms an ellipsoidal distribution in a multispace, is subdivided into two or more spherical groups (Everitt 1977; Rohlf 1967). However, when elemental intercorrelation is considered, some of the specimens that were originally not identified as members of the reference group exhibit a strong probability of belonging to that group. Thus, these samples should be added to the reference group. Then, the variance-covariance matrix of that group and the probabilities of group membership can be recalculated.

Experience has shown that the process of group refinement requires at least a 2 to 1, and preferably a 3 to 1, ratio of samples to variables for more "realistic" calculated probabilities of group membership (Rao 1948). Small groups of samples, such as the one defined for the Allentown specimens, are difficult to evaluate statistically. Although the Allentown specimens did cluster on one branch of the dendrogram and were separated from the specimens in the Chaco Canyon group, they did not display a strong degree of intersample similarity. Therefore, their retention here as a group is based on their occurrence together on the dendrogram and their low probability of belonging to the Canyon group ($p<0.01$).

Although the same computational procedures were used to form, evaluate, and refine the various groups of vessels discussed in this paper, different graphical techniques were used to display the relationships between these groups. The graph comparing the large Chaco Canyon group with the small Allentown group (Figure 3) was based on the results of a multivariate analysis. The variance-covariance matrix for the final Chaco group defined a series of 14 normalized eigenvectors, which were independent, linear combinations of the original 14 elemental determinations. The values of these vectors were calculated for each sample in both the Chaco and Allentown groups.

For the graphical comparison of the Chaco Canyon and Black Mesa groups (Figure 4), eigenvectors were not used. Although both groups were large, only the Chaco group was sufficiently refined to serve as a reference group. Samples of a well-defined, comparative group will tend to diverge in a patterned manner from a reference group centroid along the eigenvectors of the reference group. However, the Black Mesa group was not well defined. Accordingly, the samples placed within this heuristically formed group would have diverged from the Chaco group in several directions. In order to demonstrate as simply as possible that the Chaco group tended to be compositionally distinct from the Black Mesa samples, the original data recorded for pairs of elements were plotted. While it must be remembered that the groups shown on Figure 4 were separated at the 95 percent confidence level in the multidimensional space, the differentiation of the Chaco and Black Mesa groups can be also be depicted graphically in two dimensional, elemental concentration space.

REFERENCES

Bishop, Ronald L.

1980 Aspects of Compositional Modeling. In *Models and Methods in Regional Exchange*, edited by Robert E. Fry, pp. 47-66. Society for American Archaeology Papers No. 1.

Bishop, Ronald L., Garman Harbottle, and Edward V. Sayre

1982 Chemical and Mathematical Procedures Employed in the Maya Fine Paste Ceramics Project. In *Excavations at Seibal*, edited by Jeremy A. Sabloff, pp. 272-282. Memoirs of the Peabody Museum of Archaeology and Ethnology 15(2). Harvard University, Cambridge, Massachusetts.

Bishop, Ronald L., and Hector Neff

1989 Compositional Data Analysis in Archaeology. In *Archaeological Chemistry IV*, edited by Ralph O. Allen, pp. 57-86. Advances in Chemistry, Series 220. American Chemical Society, Washington, D.C.

Bishop, Ronald L., Robert L. Rands, and George R. Holley

1982 Ceramic Compositional Analysis in Archaeological Perspective. In *Advances in Archaeological Method and Theory*, vol. 5, edited by Michael B. Schiffer, pp. 275-331. Academic Press, New York.

Deutchman, Haree L.

1979 *Intra-regional Interaction on Black Mesa among the Kayenta Anasazi: The Chemical Evidence for Prehistoric Exchange*. Unpublished Ph.D. dissertation, Department of Anthropology, Southern Illinois University, Carbondale.

1980 Chemical Evidence of Ceramic Exchange on Black Mesa. In *Models and Methods in Regional Exchange*, edited by Robert E. Fry, pp. 119-134. Society for American Archaeology Papers No. 1.

Everitt, Brian

1977 *Cluster Analysis*. Heinemann Educational Books, London.

Franklin, Hayward H.

1982 Ceramic Analysis for Nineteen Sites in the Bis Sa'ani Community, Alamito Coal Lease, Northwestern New Mexico. In *Bis Sa'ani: A Late Bonito Phase Community on Escavada Wash, Northwest New Mexico*, vol. 3, edited by Cory D. Breternitz, David E. Doyel, and Michael P.Marshall, pp. 873-934. Navajo Nation Papers in Anthropology No. 14. Window Rock, Arizona.

Hantman, Jeffrey, and Stephen Plog

1982 The Relationship of Stylistic Similarity to Patterns of Material Exchange. In *Contexts for Prehistoric Exchange*, edited by Jonathan E. Ericson and Timothy K. Earle, pp.237-263. Academic Press, New York.

Hantman, Jeffrey, Steadman Upham, Kent Lightfoot, Fred Plog, Stephen Plog, and Bruce Donaldson

1984 Cibola White Wares: A Regional Perspective. In *Regional Analysis of Prehistoric Ceramic Variation: Contempoary Studies of the Cibola White Wares*, edited by Allan P. Sullivan and Jeffrey L. Hantman, pp. 17-35. Anthropological Research Papers No. 31. Arizona State University, Tempe.

Harbottle, Garman

1976 Activation Analysis in Archaeology. *Radiochemistry* 3:33-73.

1982 Chemical Characterization in Archaeology. In *Contexts for Prehistoric Exchange*, edited by Jonathan E. Ericson and Timothy K. Earle, pp. 13-52. Academic Press, New York.

Hawley, Florence M.

1934 *The Significance of the Dated Prehistory of Chetro Ketl, Chaco Canyon, New Mexico*. University of New Mexico Bulletin, Monograph Series 1(1). Albuquerque.

Hayes, Alden C., David M. Brugge, and W. James Judge

1981 *Archaeological Surveys of Chaco Canyon, New Mexico*. USDI, National Park Service, Washington, D.C.

Judd, Neil M.

1954 *The Material Culture of Pueblo Bonito*. Smithsonian Miscellaneous Collections No. 124. Smithsonian Institution, Washington, D.C.

1959 *Pueblo del Arroyo, Chaco Canyon, New Mexico*. Smithsonian Miscellaneous Collections No. 138(1). Smithsonian Institution, Washington, D.C.

1964 *The Architecture of Pueblo Bonito*. Smithsonian Institution Miscellaneous Collections No. 147(1). Smithsonian Institution, Washington, D.C.

Judge, W. James

1979 The Development of a Complex Cultural Ecosystem in the Chaco Basin, New Mexico. In *Proceedings: The First Conference on Scientific Research in the National Parks*, edited by Robert M. Linn, pp. 901-905. USDI, National Park Service, Washington D.C.

Loose, Richard W.

1977 Petrographic Notes on Selected Lithic and Ceramic Materials. In *Settlement and Subsistence along the Lower Chaco River*, edited by Charles A. Rehrer, pp. 567-571. University of New Mexico Press, Albuquerque.

McKenna, Peter J.

1984 *The Architecture and Material Culture of 29SJ1360*. Reports of the Chaco Center No. 7. USDI, National Park Service, Albuquerque.

Marshall, Michael P., John R. Stein, Richard W. Loose, and Judith E. Novotny
1979 *Anasazi Communities of the San Juan Basin*. Public Service Company of New Mexico and State of New Mexico Historic Preservation Bureau, Santa Fe.

Neitzel, Jill E.
1985 Regional Styles and Organizational Hierarchies: The View from Chaco Canyon. Paper presented at the 50th Annual Meetings of the Society for American Archaeology, Denver.
1989a The Chacoan Regional System: Interpreting the Evidence for Sociopolitical Complexity. In *The Sociopolitical Structure of Prehistoric Southwestern Societies*, edited by Steadman Upham, Kent Lightfoot, and Roberta Jewett, pp. 509-556. Westview Press, Boulder, Colorado.
1989b Regional Exchange Networks in the American Southwest: A Comparative Analysis of Long Distance Trade Goods. In *The Sociopolitical Structure of Prehistoric Southwestern Societies*, edited by Steadman Upham, Kent Lightfoot, and Roberta Jewett, pp. 149-198. Westview Press, Boulder, Colorado.
1991 Elite Styles in Hierarchically Organized Societies: Expectations and Evidence from the Chacoan Regional System. In *Style, Society, and Person*, edited by Christopher Carr and Jill E. Neitzel. Cambridge University Press, Cambridge, England. (in press)

Pepper, George H.
1920 *Pueblo Bonito*. Anthropological Papers of the American Museum of Natural History No. 27. New York.

Plog, Stephen
1990 Sociopolitical Implications of Southwestern Stylistic Variation. In *The Use of Style in Archaeology*, edited by Margaret Conkey and Christine Hasdorf. Cambridge University Press, Cambridge, England. (in press)
1991 Approaches to the Study of Style: Complements and Contrasts. In *Style, Society, and Person*, edited by Christopher Carr and Jill E. Neitzel. Cambridge University Press, Cambridge, England. (in press)

Plog, Stephen, and Jeffrey Hantman
1986 Multiple Regression Analysis As a Dating Method in the American Southwest. In *Spatial Organization and Exchange on Black Mesa*, edited by Stephen Plog, pp. 87-113. Southern Illinois University Press, Carbondale.

Powers, Robert P., William B. Gillespie, and Stephen H. Lekson
1983 *The Outlier Survey: A Regional View of Settlement in the San Juan Basin*. Reports of the Chaco Center No. 3. USDI, National Park Service, Albuquerque.

Rao, Calyampudi Radhakrishna
1948 Tests of Significance in Multivariate Analysis. *Biometrika* 35:58-79.

Roberts, Frank H.H.
1927 *The Ceramic Sequence in Chaco Canyon, New Mexico and Its Relations to the Culture of the San Juan Basin*. Unpublished Ph.D. dissertation, Department of Anthropology, Harvard University, Cambridge.
1939 Archaeological Remains in the Whitewater District of Eastern Arizona, Part 1: House Types. *Bureau of American Ethnology Bulletin* No. 121. U.S. Government Printing Office, Washington, D.C.
1940 Archaeological Remains in the Whitewater District, Eastern Arizona, Part II: Artifacts. *Bureau of American Ethnology Bulletin* No. 126. U.S. Government Printing Office, Washington, D.C.

Rohlf, F. James
1967 Correlated Characters in Numerical Taxonomy. *Systematic Zoology* 16:109-126.

Schelberg, John D.
1982 *Economic and Social Development as an Adaptation to the Marginal Environment in Chaco Canyon, New Mexico*. Unpublished Ph.D. dissertation, Department of Anthropology, Northwestern University, Evanston.

Shepard, Anna O.
1939 Technology of La Plata Pottery. In *Archaeological Studies in the La Plata District*,

by Earl H. Morris, pp. 249-287. Carnegie Institute of Washington Publication No. 519. Washington, D.C.

Toll, H. Wolcott
1981 Ceramic Comparisons Concerning Redistribution in Chaco Canyon, New Mexico. In *Production and Distribution: A Ceramic Viewpoint*, edited by Hilary Howard and Elaine L. Morris, pp. 83-122. British Archaeological Reports, International Series No. 120. Oxford, England.
1984 Trends in Ceramic Import and Distribution in Chaco Canyon. In *Recent Research on Chaco Prehistory*, edited by W. James Judge and John D. Schelberg, pp. 115-135. Reports of the Chaco Center No. 8. USDI, National Park Service, Albuquerque.
1985 *Pottery, Production, Public Architecture, and the Chaco Anasazi System*. Unpublished Ph.D. dissertation, Department of Anthropology, University of Colorado, Boulder.

Toll, H. Wolcott, Thomas C. Windes, and Peter J. McKenna
1980 Late Ceramic Patterns in Chaco Canyon: The Pragmatics of Modeling Ceramic Exchange. In *Models and Methods in Regional Exchange*, edited by Robert E. Fry, pp. 95-118. Society for American Archaeology Papers No. 1.

Warren, A. Helene
1967 Petrographic Analyses of Pottery and Lithics. In *An Archaeological Survey of the Chuska Valley and the Chaco Plateau, New Mexico*, by Arthur H. Harris, James Schoenwetter, and A. Helene Warren, pp. 104-134. Museum of New Mexico Research Records No. 4. Albuquerque.

Washburn, Dorothy K.
1980 The Mexican Connection: Cylinder Jars from the Valley of Oaxaca. *Transactions of the Illinois Academy of Science* 72(4): 70-85.

Windes, Thomas C.
1977 Typology and Technology of Anasazi Ceramics. In *Settlement and Subsistence along the Lower Chaco River: The CGP Survey*, edited by Charles A. Rehrer, pp. 279-358. University of New Mexico Press, Albuquerque.
1984 View of the Cibola White Ware from Chaco Canyon. In *Regional Analysis of Prehistoric Ceramic Variation: Contemporary Studies of the Cibola Whitewares*, edited by Allan P. Sullivan and Jeffrey L. Hantman, pp. 94-119. Arizona State University Anthropological Research Papers No. 31. Tempe.